1. SPENT NUCLEAR FUEL

1.1 INTRODUCTION

This chapter reports both the quantities and characteristics of spent nuclear fuel (SNF) that has been permanently discharged from commercial light-water reactors (LWRs) and one-of-a-kind reactors. In addition, this chapter contains a mass summary report of U.S. Department of Energy (DOE) SNF (see Sect. 1.4). Though currently in storage at numerous commercial and DOE sites, this fuel will ultimately require geologic disposal.

Some commercial SNF in inventory will be reinserted into reactors for further irradiation. However, this amount is relatively small, and the schedules for reinsertions are not always predictable. Therefore, in this report, all SNF is considered to be permanently discharged from the reactors.

Historical inventories of commercial LWR SNF have been updated through December 31, 1995.[1] The data reported in this chapter include the inventories of SNF stored at the West Valley Demonstration Project (WVDP), the Midwest Fuel Recovery Plant (MFRP), the Idaho National Engineering and Environmental Laboratory (INEEL), and other DOE sites in addition to those stored at the various reactor sites. The current locations of existing and planned power reactor sites and commercial LWR SNF storage facilities are given in report DOE/OSTI-8200-R60 (ref. 2).

Projections of nuclear capacity and SNF discharges are given for the calendar years (CYs) 1997–2030 for the DOE/Energy Information Administration (EIA) Reference Case forecast schedule reported in ref. 3. Starting with an estimate for 1997 of 100.7 GW(e), the Reference Case forecast projects installed commercial nuclear electric capacity to start declining in the year 1999, ultimately decreasing to 2.3 GW(e) by 2030.

The Reference Case scenario for projecting accumulated SNF assumes a nuclear fuel cycle that does not have any fuel reprocessing. SNF discharge projections, in terms of cumulative mass discharged, are graphically illustrated in Fig. 1.1.

DOE/EIA projections for the Reference Case assume that current average equilibrium burnup levels of discharged SNF will be 33,000 and 41,000 megawatt day (MWd)/metric tons of initial heavy metal (MTIHM) for boiling-water reactor (BWR) and pressurized-water reactor (PWR) fuel, respectively.[3]

1.2 COMMERCIAL SPENT NUCLEAR FUEL

1.2.1 Inventories and projections

The total inventory of commercial LWR SNF in storage at the WVDP site, the MFRP, DOE sites, and the reactor sites as of December 31, 1996, is estimated to be over 34,000 MTIHM. Of this total amount, 26 MTIHM are stored at the WVDP site,[4] 674 MTIHM are stored at the MFRP,[1] 171 MTIHM are stored at INEEL,[4] and about 25 MTIHM are stored at other DOE sites. The remainder is stored at the reactor sites. These inventories do not include the SNF reprocessed at the WVDP site when the facility was operated as a fuel reprocessing plant. The WVDP SNF inventories include 125 LWR fuel assemblies (representing 26 MTIHM), which are owned by DOE.

A BWR/PWR breakdown of the electric power generating capacity for the Reference Case forecast, along with historical reactor capacity data, is given in Table 1.1. The buildups of permanently discharged LWR SNF mass are given on a historical basis in Table 1.2 and for the projected DOE/EIA Reference Case in Table 1.3.

1.2.2 Characterization

Reference characteristics of BWR and PWR fuel assemblies, obtained from refs. 5 and 6, are summarized in Table 1.4. More detailed information on SNF characteristics may be found in ref. 7.

1.3 DISPOSAL

The DOE Office of Civilian Radioactive Waste Management (OCRWM) has been focused on characterization of the Yucca Mountain site to address suitability of the site. The approach has been refined to structure a multi-staged process for arriving at a site suitability determination. This process calls for an assessment to be made in 1998 of the viability of siting a repository at Yucca Mountain and an updating of the regulatory framework for siting a repository. Excavation of the main tunnel of the Exploratory Shaft Facility was completed in April 1997. Extensive surface-based and underground testing are still being conducted.

OCRWM is developing an approach for the performance of its waste acceptance, storage, and transportation responsibilities, as set forth in the Nuclear Waste Policy Act (NWPA), as amended, and in the Standard Contract for disposal of SNF and HLW (see Glossary of Terms). A presolicitation conference was held July 9, 1996, to discuss technical and contractual issues related to the potential acquisition of transportation services. At the presolicitation conference, OCRWM made available a draft Statement of Work and a draft Concept of Operations for the waste acceptance and transportation services acquisition. A draft request for proposals (RFP) was issued for public review and comment in December 1996, followed by another presolicitation conference in March 1997.

OCRWM is pursuing an acquisition process that is market-driven, relying on private industry (contractors) to provide all necessary services and equipment to fulfill OCRWM's mission at competitive fixed prices and fixed rates. The contractors would accept SNF from its owners and generators (purchasers) and supply casks and equipment for transporting SNF to (and possibly storage at) a designated federal facility. Contractors would work with purchasers to determine the best way to service a site and would recommend to the NRC preferred transportation routes to a federal facility.

OCRWM may award up to four contracts, covering four regions of the United States. The intent is to develop a market infrastructure to foster competition and innovative approaches to waste acceptance and transportation.

1.4 DOE SPENT NUCLEAR FUEL

Summary inventory characteristics of DOE SNF as of June 1997 are given in Table 1.5 (based on ref. 4). Projected site inventories for CY 2035 are also included. Figure 1.2 shows the major locations and masses of current DOE SNF inventories.

For clarification, the quantities of SNF reported in Table 1.5 include contributions from other nuclear fuels besides those permanently discharged from production reactors. SNFs reported in this table also include DOE-owned nuclear fuel that has been withdrawn from or resides for storage in a nuclear reactor following irradiation, the constituent elements of which have not been separated by processing. In addition to intact fuel, reactor-irradiated fuel materials requiring special handling (e.g., defective fuel and special fuel forms) are also considered SNF and are eligible for inclusion in Table 1.5. This table also lists some commercially generated nuclear fuels and nuclear fuels from foreign research reactors (FRRs) and university research reactors which are stored at DOE sites. More detailed information on these special nuclear fuels will be included in future updates of this report.

Major changes in the DOE SNF inventories reported in Table 1.5 that have occurred since the last publication of this document are attributed to the following:

- SNF at LANL has been moved to SRS;
- SRS has also received shipments of SNF from several universities, non-DOE-owned research reactors, and FRRs;
- Inventories of naval SNF at INEEL have increased, and most SNF that was previously stored at the INEEL ICPP-603 facility has been removed;
- At McClellan Air Force Base, inventories of Training Reactor, Isotopes, General Atomics (TRIGA) fuel have increased; and
- About 167 MTIHM of SNF has been processed at SRS and Argonne National Laboratory–West (ANL–W), and the resulting waste is now listed as high-level waste (HLW).

1.5 REFERENCES

1. U.S. Department of Energy, Energy Information Administration, Nuclear Fuel Data Form RW-859, Washington, D.C. (historical data as of December 31, 1995).

2. U.S. Department of Energy, Office of Scientific and Technical Information, *Nuclear Reactors Built, Being Built, or Planned: 1996*, DOE/OSTI-8200-R60, Oak Ridge, Tennessee (August 1997).

3. U.S. Department of Energy, Energy Information Administration, *Nuclear Power Generation and Fuel Cycle Report 1997*, DOE/EIA-0436(97), Washington, D.C. (September 1997).

4. Elwood P. Stroupe, National Spent Nuclear Fuel Program, Idaho National Engineering Laboratory, Idaho Falls, Idaho, correspondence to Stephen N. Storch, IDB Program, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Spent Fuel Data for the Integrated Data Base," EPS-36-97, dated July 14, 1997.

5. General Electric Company, *General Electric Standard Safety Analysis Report*, BWR/6, Docket STN 50-447, San Jose, California (1973).

6. Westinghouse Nuclear Energy Systems, *Reference Safety Analysis Report*, RESAR-3, Docket STN 50-480, Pittsburgh, Pennsylvania (1972).

7. U.S. Department of Energy, *Characteristics of Potential Repository Wastes*, Vols. 1–4, DOE/RW-0184-R1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (July 1992).

Table 1.1. Historical and projected installed LWR electric power generating capacity for the DOE/EIA Reference Case

End of CY	Historical capacity[a] [GW(e)]			End of CY	Reference Case projected capacity[b] [GW(e)]		
	BWR	PWR	Total		BWR	PWR	Total
1960	0.1	0.2	0.3	1997	33.6	67.1	100.7
1961	0.1	0.2	0.3	1998	33.6	67.1	100.7
1962	0.1	0.2	0.4	1999	33.1	66.3	99.4
1963	0.1	0.2	0.4	2000	33.1	66.3	99.4
1964	0.1	0.2	0.4	2001	33.1	66.3	99.4
1965	0.1	0.2	0.4	2002	32.7	65.3	98.0
1966	0.1	0.2	0.4	2003	32.7	65.3	98.0
1967	0.1	1.3	1.4	2004	31.9	63.9	95.8
1968	0.2	1.2	1.4	2005	31.7	63.3	95.0
1969	0.8	1.7	2.6	2006	31.1	62.3	93.4
1970	2.9	2.9	5.8	2007	30.9	61.9	92.8
1971	4.3	3.7	8.0	2008	30.7	61.3	92.0
1972	7.0	6.5	13.5	2009	30.5	61.0	91.5
1973	8.1	14.1	22.1	2010	29.7	59.4	89.1
1974	13.3	19.4	32.7	2011	29.4	58.9	88.3
1975	15.0	23.3	38.3	2012	28.3	56.5	84.8
1976	16.8	27.9	44.7	2013	24.5	49.0	73.5
1977	16.8	30.4	47.2	2014	21.6	43.2	64.8
1978	17.6	32.2	49.8	2015	21.0	42.0	63.0
1979	17.6	32.2	49.8	2016	19.2	38.3	57.5
1980	17.6	34.3	51.9	2017	18.3	36.5	54.8
1981	17.6	38.6	56.2	2018	17.4	34.8	52.2
1982	18.7	40.5	59.2	2019	17.4	34.8	52.2
1983	19.7	43.6	63.3	2020	16.4	32.7	49.1
1984	24.2	45.8	70.0	2021	15.0	30.0	45.0
1985	26.8	51.7	78.5	2022	13.6	27.2	40.8
1986	28.9	55.2	84.1	2023	12.2	24.5	36.7
1987	31.8	60.8	92.6	2024	9.6	19.2	28.8
1988	31.8	63.1	94.9	2025	7.4	14.7	22.1
1989	33.8	64.1	97.9	2026	4.2	8.4	12.6
1990	32.9	66.7	99.6	2027	2.3	4.7	7.0
1991	32.0	67.7	99.6	2028	1.1	4.6	5.7
1992	31.8	67.1	98.9	2029	0.0	3.5	3.5
1993	31.8	67.2	99.0	2030	0.0	2.3	2.3
1994	31.9	67.2	99.1				
1995	32.2	67.2	99.4				
1996	32.2	68.5	100.7				

[a]Based on ref. 1.

[b]Data from ref. 3. Assumes that no new reactors will be ordered. Projections assume that one-third of the total capacity will be provided by BWRs and the remainder by PWRs.

Table 1.2. Historical mass (MTIHM) of permanently discharged commercial SNF by reactor type[a]

End of CY	BWR[b]		PWR[c]		Total LWR[d]	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1968–1970		16		39		55
1971	65	81	44	83	109	164
1972	146	226	100	183	246	410
1973	94	320	67	250	161	570
1974	242	562	208	458	449	1,020
1975	226	787	322	780	548	1,567
1976	298	1,085	401	1,181	699	2,266
1977	383	1,469	467	1,648	850	3,116
1978	384	1,852	699	2,346	1,082	4,199
1979	400	2,252	721	3,068	1,121	5,320
1980	620	2,872	618	3,686	1,238	6,558
1981	459	3,331	676	4,362	1,135	7,692
1982	357	3,688	640	5,002	998	8,690
1983	491	4,179	771	5,773	1,263	9,952
1984	498	4,677	841	6,614	1,339	11,291
1985	532	5,209	861	7,475	1,393	12,684
1986	458	5,667	996	8,472	1,454	14,139
1987	597	6,264	1,109	9,581	1,706	15,844
1988	536	6,799	1,117	10,697	1,652	17,497
1989	698	7,497	1,215	11,913	1,913	19,410
1990	633	8,130	1,504	13,417	2,137	21,547
1991	588	8,718	1,271	14,688	1,859	23,406
1992	695	9,413	1,596	16,284	2,291	25,697
1993	700	10,113	1,532	17,816	2,232	27,929
1994	675	10,788	1,207	19,024	1,882	29,811
1995	627	11,415	1,514	20,538	2,141	31,952[e]
1996[f]	690	12,105	1,610	22,148	2,300	34,252

[a]Based on refs. 1 and 3.
[b]BWR = boiling-water reactor.
[c]PWR = pressurized-water reactor.
[d]LWR = light-water reactor.
[e]Excludes 70 MTIHM of discharged fuel assemblies that are expected to be reinserted.
[f]Data reported are based on last year's projection for CY 1996.

Table 1.3. Current and projected mass (MTIHM) of permanently discharged commercial LWR SNF for the DOE/EIA Reference Case[a]

End of CY	Annual	Cumulative
1996[b]	2,300	34,252
1997	2,100	36,300
1998	2,300	38,600
1999	2,400	41,000
2000	2,300	43,300
2001	2,100	45,500
2002	2,200	47,600
2003	2,200	49,800
2004	1,900	51,700
2005	2,500	54,200
2006	1,600	55,800
2007	2,000	57,800
2008	1,800	59,600
2009	1,800	61,400
2010	2,000	63,400
2011	1,300	64,700
2012	2,100	66,800
2013	2,200	69,000
2014	2,400	71,400
2015	1,000	72,400
2016	1,800	74,100
2017	1,100	75,200
2018	1,200	76,400
2019	900	77,300
2020	1,100	78,500
2021	1,100	79,500
2022	1,400	81,000
2023	900	81,800
2024	1,500	83,300
2025	1,000	84,200
2026	1,300	85,500
2027	600	86,100
2028	200	86,300
2029	300	86,600
2030	100	86,700

[a]Assumes no future fuel reprocessing. Note that cumulative levels reported may not equal sum of annual additions because of independent rounding.

[b]Data reported as based on last year's projection for CY 1996.

Table 1.4. IDB reference characteristics of LWR nuclear fuel assemblies

Characteristics	BWR[a]	PWR[b]
Overall assembly length, m	4.470	4.059
Cross section, cm	13.9 × 13.9	21.4 × 21.4
Fuel rod length, m	4.064	3.851
Active fuel height, m	3.759	3.658
Fuel rod outer diameter, cm	1.252	0.950
Fuel rod array	8 × 8	17 × 17
Fuel rods per assembly	63	264
Assembly total weight, kg	319.9	657.9
Uranium/assembly, kg	183.3	461.4
UO_2/assembly, kg	208.0	523.4
Zircaloy/assembly, kg	103.3[c]	108.4[d]
Hardware/assembly, kg	8.6[e]	26.1[f]
Total metal/assembly, kg	111.9	134.5
Nominal volume/assembly, m^3	0.0864[g]	0.186[g]

[a]Ref. 5.
[b]Ref. 6.
[c]Includes Zircaloy fuel-rod spacers and fuel channel.
[d]Includes Zircaloy control-rod guide thimbles.
[e]Includes stainless steel tie-plates, Inconel springs, and plenum springs.
[f]Includes stainless steel nozzles and Inconel-718 grids.
[g]Based on overall outside dimension. Includes spacing between the stacked fuel rods of an assembly.

Table 1.5. Summary inventory of DOE SNF for years 1997 and 2035[a]

Site/category	Facility[b]	1997 total mass (kg)	1997 volume (m^3)	Discharged heavy metal (MTHM)	
				1997	2035
ANL–E	Alpha-gamma hot cell	257.10	0.10	0.08	0.08
	Chicago Pile-5	12.80	0.01	0.00	0.00
	Subtotal	269.90	0.12	0.08	0.08
ANL–W	FCF	543.81	0.09	0.18	0.18
	HFEF	6,598.23	1.02	1.94	1.94
	RSWF	33,469.78	3.04	26.05	26.05
	TREAT	206.81	4.95	0.02	0.02
	Subtotal	40,818.63	9.11	28.20	28.20
BNL	BMRR	165.46	0.13	0.00	0.01
	HFBR	3,650.21	7.24	0.22	1.35
	Subtotal	3,815.67	7.37	0.23	1.36
FRR	FRR				16.15
FSVR	ISFSI	187,392.00	130.27	14.73	14.73
Hanford	Area 200 (burial)	808.78	4.41	0.32	0.32
	Area 400 (ISA)	350.60	0.08	0.02	0.02
	Area 618 (burial)	0.00	0.00	0.00	0.00
	Bldg. 324	4,077.50	1.19	2.28	2.28
	Bldg. 325	50.00	0.01	0.01	0.01
	Bldg. 327	39.00	0.01	0.02	0.02
	FFTF	130,223.38	40.67	10.99	10.99
	PFP	1,023.40	0.02	0.01	0.01
	T-plant	38,500.00	9.45	15.82	15.82
	105-K East Basin	1,723,772.00	99.94	1,146.43	1,146.43
	105-K West Basin	1,806,522.00	104.56	957.16	957.16
	Subtotal	3,705,366.66	260.34	2,133.06	2,133.06
INEEL	ICPP-603	11,115.48	6.57	1.81	1.81
	ICPP-666	394,143.02	174.53	15.94	15.94
	ICPP-749	204,181.88	47.90	78.59	78.59
	ICPP-IFSF	131,390.79	86.11	10.02	10.02
	MTR canal	1,990.70	0.75	0.26	0.26
	PER-620	5,580.50	0.84	0.56	0.56
	TAN-607	333,480.56	131.85	85.29	85.29
	TAN-791	55,275.81	10.67	38.37	38.37
	TRA-660	577.62	0.46	0.23	0.23
	TRA-670	8,240.00	9.73	0.73	2.47
	Subtotal	1,145,976.36	469.39	231.80	233.54
INEEL/NRF	ECF	347,784.67	80.34	5.61	5.61

Table 1.5 (continued)

Site/category	Facility[b]	1997 total mass (kg)	1997 volume (m^3)	Discharged heavy metal (MTHM)	
				1997	2035
ORNL	Bldg. 7827	1,978.90	4.01	0.15	0.15
	Bldg. 7829	782.40	0.48	0.03	0.03
	Bldg. 7920	204.30	0.10	0.00	0.00
	Bldg. 7900 pools	9,373.30	7.98	0.47	1.14
	BSR	327.04	0.40	0.06	0.06
	MSR	8,940.00	3.88	0.04	0.04
	TSR	182.00	0.10	0.01	0.01
	Subtotal	21,787.94	16.94	0.76	1.42
SNL/NM	ACRR	100.00	0.09	0.00	2.36
	Dense pack	900.00	1.12	0.10	0.10
	Manzano storage	12,800.00	5.20	0.00	0.00
	Subtotal	13,800.00	6.40	0.10	2.46
SRS	RBOF	217,285.03	89.11	40.02	40.02
U.S. Navy	U.S. Navy Shipyards				49.35
WVDP	Fuel Receiving and Storage Facility	42,780.00	11.34	26.31	26.31
Other	Non-DOE-owned domestic reactors				
	Armed Forces Radiobiological Facility	323.00	0.08	0.02	0.02
	ARRR	263.90	0.07	0.01	0.01
	DOW TRIGA Reactor	265.20	0.06	0.01	0.01
	GA TRIGA Reactor Facility	884.60	0.22	0.06	0.06
	GE Pleasanton	80.00	0.05	0.01	0.01
	Hot cell facility (GA)	28.90	0.08	0.01	0.01
	Lynchburg Technology Center	77.05	0.03	0.04	0.04
	MNRC	570.80	0.13	0.04	0.04
	NBSR	830.98	2.16	0.02	0.11
	Omaha VA Medical Center	162.40	0.04	0.01	0.01
	USGS Facility of Denver, Colorado	547.40	0.13	0.03	0.04
	Subtotal	4,057.43	3.05	0.27	0.37
	University				
	Cornell University	418.20	0.10	0.02	0.03
	Georgia Institute of Technology	0.00	0.00	0.00	0.15
	Iowa State University Reactor	38.55	0.19	0.02	0.02
	Kansas State University	377.40	0.09	0.02	0.03
	Massachusetts Institute of Technology	304.00	0.20	0.03	0.12
	North Carolina State University	880.00	0.24	0.53	0.53
	Ohio State University	200.00	2.14	0.03	0.03
	Oregon State University	336.80	0.08	0.02	0.03
	Pennsylvania State University	615.40	0.15	0.04	0.04
	Purdue University	3.72	0.01	0.00	0.03

Table 1.5 (continued)

Site/category	Facility[b]	1997 total mass (kg)	1997 volume (m^3)	Discharged heavy metal (MTHM)	
				1997	2035
Other (contd.)	University (contd.)				
	Reed Reactor Facility	227.80	0.06	0.01	0.01
	Rhode Island Nuclear Science Center	99.00	0.10	0.02	0.17
	State University of New York–Buffalo	1,000.00	0.13	0.66	0.66
	Texas A&M	632.40	0.15	0.03	0.08
	University of California–Irvine	384.20	0.09	0.02	0.02
	University of Massachusetts–Lowell	230.00	0.15	0.00	0.05
	University of Texas–Austin	533.80	0.13	0.03	0.03
	University of Arizona	333.20	0.08	0.02	0.02
	University of Florida	313.00	0.66	0.01	0.03
	University of Illinois	698.90	0.17	0.04	0.05
	University of Maryland	316.20	0.08	0.02	0.03
	University of Michigan	598.00	0.71	0.10	0.47
	University of Missouri[c]	806.00	0.97	0.09	0.59
	University of Utah	425.40	0.12	0.03	0.04
	University of Virginia	191.40	0.19	0.04	0.09
	University of Wisconsin	775.20	0.19	0.04	0.09
	Washington State University	731.00	0.18	0.04	0.09
	Worcester Institute of Technology	150.80	0.16	0.02	0.02
	Subtotal	11,620.37	7.52	1.92	3.56
	Grand total	5,742,754.67	1,091.30	2,483.09	2,556.21

[a]Based on ref. 4. Inventories for 1997 are reported as of June 1997.

[b]Abbreviations used in this table: ACRR—Annular Core Research Reactor, ARRR—Aerotest Radiography and Research Reactor, BMRR–Brookhaven Medical Research Reactor, BSR—Bulk Shielding Reactor, CMR—Chemistry and Metallurgical Research, ECF—Extended Core Facility, FCF—Fuel Conditioning Facility, FFTF—Fast Flux Test Facility, FRR—Foreign Research Reactor, FSVR—Fort St. Vrain Reactor, GA—General Atomics, GE—General Electric, HCF—Hot Cell Facility, HFBR—(Brookhaven) High Flux Beam (Research) Reactor, HFEF—Hot Fuel Examination Facility, ICPP—Idaho Chemical Processing Plant, IFSF—Irradiated Fuel Storage Facility, ISA—Interim Storage Area, ISFSI—Independent Spent Fuel Storage Installation, MNRC—McClellan Nuclear Radiation Center, MSR—Molten Salt Reactor, MTR—Materials Test Reactor, NBSR—National Bureau of Standards Reactor, PER—(Special) Power Excursion Reactor (Test), PFP—plutonium finishing plant, RBOF—Receiving Basin for Off-Site Fuels, RSWF—Radioactive Scrap and Waste Facility, SRTC—Savannah River Technical Center, TAN—Test Area North, TRA—Test Reactor Area, TREAT—Transient Reactor Test Facility, TRIGA—Training Reactor, Isotopes, General Atomic, TSR—Tower Shielding Reactor, USGS—U.S. Geological Survey, and VA—Veterans Administration.

[c]Includes reactors at both Columbia and Rolla.

FIG1-1

ORNL DWG 96-3532R

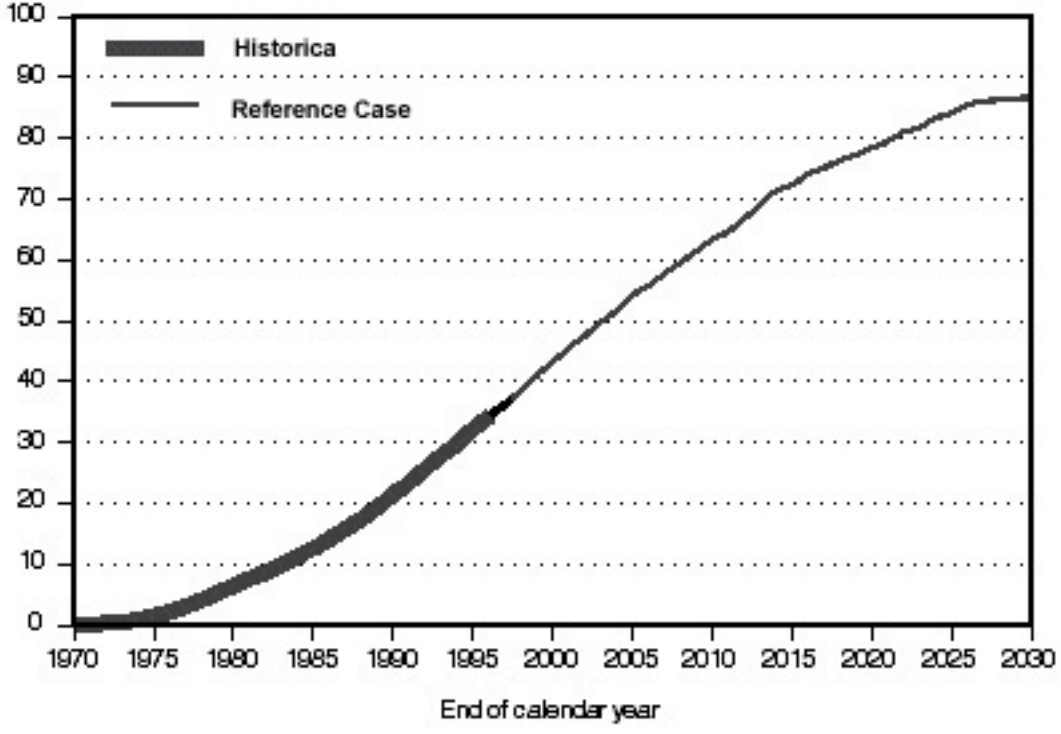
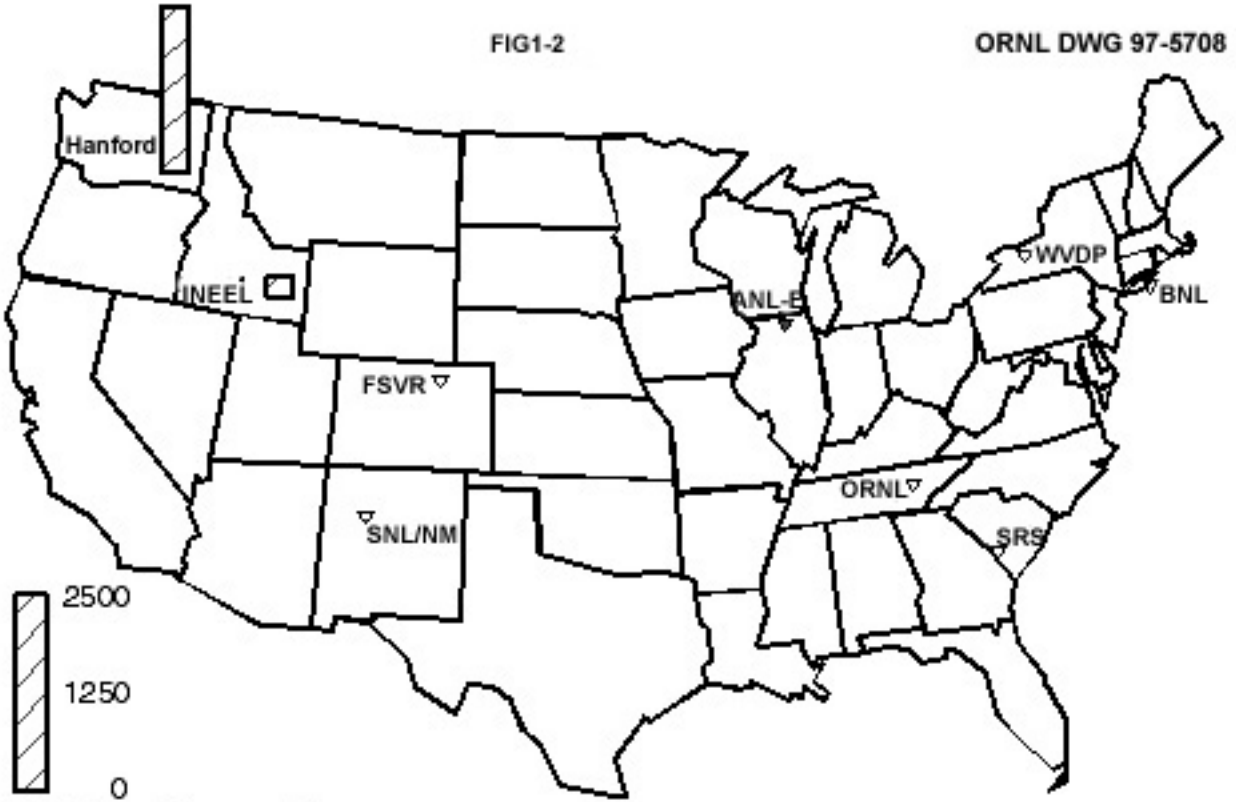


FIG1-2

ORNL DWG 97-5708



*Includes contributions from ANL-W and NRF.

Note. Only locations are shown for sites whose DOE SNF inventories are less than 50 MTHM. Excludes fuel at universities & non-DOE-owned domestic reactors.